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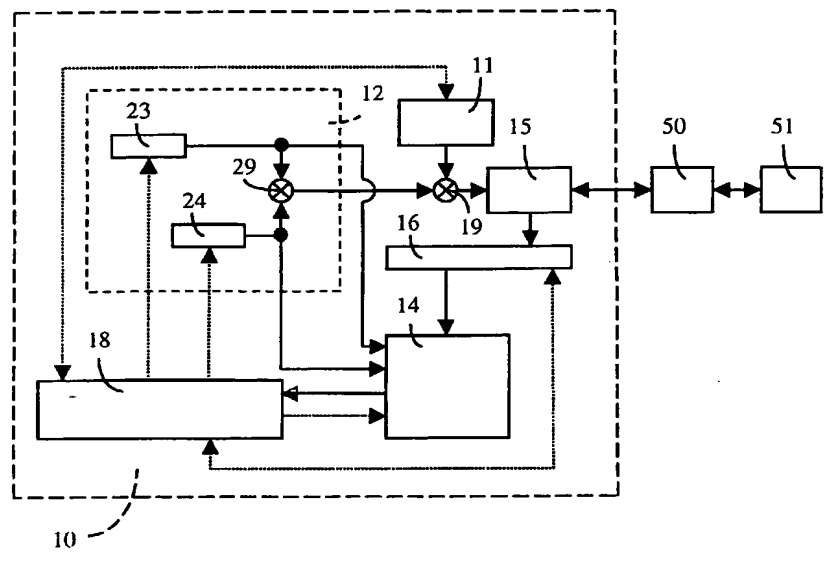
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[Continued on next page]

(54) Title: **APPARATUS AND METHOD FOR MEASURING CHROMATIC DISPERSION BY VARIABLE WAVELENGTH**



(57) Abstract: The present invention relates to an apparatus (10) that allows to characterise or measure the chromatic dispersion in an optical fibre segment (50) by accessing a single end of the fibre itself (50) and measuring the phase shift between modulating signals of impulsive kind generated by a signal generator (12) and the same modulation signals reflected by a remote end of the fibre (51). The invention further relates to the method for measuring the chromatic dispersion of the optical fibre (50). Thanks to the invention, the apparatus (10) does not require an absolute external reference signal and allows to determine the chromatic dispersion of the fibre (50) being measured as the wavelength of the optical signals varies.



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## APPARATUS AND METHOD FOR MEASURING CHROMATIC DISPERSION BY VARIABLE WAVELENGTH

**Technical Field**

The present invention relates to an apparatus for  
5 measuring Chromatic Dispersion (CD) in optical fibres, and to  
the related method.

Chromatic dispersion is a particularly important  
characteristic of optical fibres due to the distortion  
effects it causes on the optical signals that propagate in  
10 fibres for telecommunications.

Such a phenomenon is, as is well known, linked to the  
different group velocities with which various spectral  
components of optical signals propagate in a fibre, for  
instance between an optical transmitter and receiver or a  
15 first and a second end of the fibre.

The spectral components of an optical signal, due to the  
different group velocities, reach the receiver at different  
times and determine a distortion of the received signal both  
in analogue transmission systems, and in digital transmission  
20 systems.

The chromatic dispersion of optical fibres, as is well known,  
is determined mainly by two factors, the dispersion  
characteristics of the material whereof the fibres are made  
(dependence of the refractive index of the material on  
25 frequency), and the very nature of the propagation of an  
optical signal in a waveguide (the so-called "waveguide  
dispersion").

The chromatic dispersion of optical fibres can be suitably  
controlled by a careful design of the profile of the  
30 refractive index of the fibres: in fact, today optical fibres  
are manufactured with chromatic dispersion characteristics  
specifically studied to meet the requirements of the most  
sophisticated optical transmission systems.

As said requirements become ever more stringent, in particular for transmission systems with bit rates of 10 Gbit/s or higher, the need also increases to "characterise" the CD of the optical fibres with accuracy, not only in the factory during the product qualification stage, but also in

Said "characterisation" is indispensable in order to design and install new-generation transmission systems (with bit rates of 10 Gbit/s or higher) on recent fibres or to verify, in case of less recent systems, the possibility of supporting a higher transmission capacity.

#### Background Art

Today, the chromatic dispersion of optical fibres is measured by means of at least three different, consolidated techniques, as described, for instance, in the ITU-T Recommendation G.650. Amongst such techniques, one of the most commonly used is the so-called Phase Shift (or PS) technique. It consists of measuring the phase shift introduced by the optical fibre segment being measured on a sinusoidal signal that modulates an optical carrier which is made to propagate in the fibre itself. The measurement is repeated at different wavelengths of the aforesaid optical carrier and for each of them the group delay of the modulating sinusoidal signal, which is proportional to the aforesaid phase shift, is calculated.

An embodiment of an apparatus or instrument for measuring chromatic dispersion is, for instance, described in US Patent 6,313,934.

This document describes, *inter alia*, a methodology for measuring chromatic dispersion wherein the phase shift of the sinusoidal signal, that modulates the optical carrier, introduced by the fibre segment is measured by synchronising, by means of absolute timing systems obtained from a GPS (Global Positioning System), appropriate devices for

generating and measuring the sinusoidal signal, positioned at the ends of the fibre itself.

The prior art method entails the need to simultaneously access the two ends of the fibre to be characterised, to  
5 apply appropriate instrumentation to the two ends of the fibre and to use an absolute reference system with which to synchronise the instrumentation at the two ends of the fibre.

#### **Disclosure of the Invention**

Object of the present invention is a measuring apparatus  
10 and related method that does not necessarily require to access the two ends of the fibre in order to perform the chromatic dispersion measurements, nor require to use an absolute reference system to synchronise the instrumentation.

This object is achieved by the apparatus for measuring  
15 the chromatic dispersion of optical fibres and the corresponding method as claimed.

In particular, the object is achieved by the apparatus that allows to characterise or measure the chromatic dispersion or CD of a fibre segment accessing only one end of  
20 the fibre itself.

According to another characteristic of the present invention, the apparatus does not require absolute external reference signal, but has within it all that is necessary to determine the chromatic dispersion of the fibre being  
25 measured.

#### **Brief Description of Drawings**

This and other characteristics of the present invention shall become readily apparent from the following description of a preferred embodiment, made purely by way of non limiting  
30 example with the aid of the accompanying drawings, in which:  
Fig. 1 shows a block diagram of the apparatus for measuring chromatic dispersion according to the invention; and  
Fig. 2 shows an example of impulsive signal used in the apparatus of Fig. 1 to measure chromatic dispersion.

**Best mode for Carrying Out the Invention**

With reference to Fig. 1, the apparatus or instrument 10, according to the invention, comprises a tuneable source of optical signals (optical source) 11, a device for  
5 generating modulating pulses (signal generator) 12 able to modulate the optical signals generated by the optical source 11, by means of a modulator or multiplier device 19, and a coupling device 15 able to convey the modulated optical signal on an optical fibre 50 to be subjected to  
10 characterisation or analysis.

The apparatus 10 further comprises a phase comparator 14 connected at the output of an optical receiver 16 and a control processor (processor) 18 connected by means of  
15 respective control wires (shown in the figure with dashed lines) to the optical source 11, to the signal generator 12, to the phase comparator 14 and to the optical receiver 16.

The apparatus 10 is connected, by means of the coupling device 15, to a first termination of the fibre (fibre segment) 50 in correspondence with the end adjacent to the  
20 apparatus.

According to the present embodiment, the fibre segment 50 to be characterised or measured has in correspondence with the second end, in general far from the apparatus 10, a reflecting termination 51, of a known kind, constituted, for  
25 example, by a reflecting optical component, specifically connected to the end of the optical fibre to perform the characterisation, or, preferably, by a not-angled terminal connector.

The optical source 11 of the apparatus 10, known in  
30 itself, is able to generate optical signals at variable wavelength, based on commands transmitted by the processor 18 through the respective control wire and to transmit them to the modulator device (modulator) 19 to be modulated with the modulating pulses.

The signal generator 12 comprises a generator of sinusoidal signals (sinusoidal generator) 23, a generator of impulse signals (impulse generator) 24 and an associated multiplier device 29, known in themselves, and is able to generate the product of the aforesaid sinusoidal signal and of the impulse signal and to send them to the modulator 19 as modulation signals of the kind shown by way of example in Figure 2.

In particular, the modulation signals (modulating) are shaped by pulses of determined duration and periodicity in which the pulses themselves have their amplitude variable in sinusoidal fashion about a reference level.

Both the sinusoidal generator 23 and the impulse generator 24 are controlled by means of respective control wires by the processor 18 to enable varying both the characteristics of the sinusoidal signals and of the impulses.

Moreover, both the sinusoidal generator 23 and the impulse generator 24 are connected, by means of respective connections, to the phase comparator 14 and are able to transmit the respective signals to the comparator 14 itself.

The coupling device 15, known in itself, for instance constituted by a directional coupler or by an optical circulator, is able to collect the modulated optical signal coming from the multiplier 19 and to send it to the optical fibre 50 through the first termination.

The coupling device 15 is also able to collect the signals reflected back by the reflecting termination 51 and to send them, through a corresponding optical connection, to the optical receiver 16.

The optical receiver 16, of a known kind, has its input connected to the coupling device 15 and the output connected to the phase comparator 14 and it is able to detect the signals reflected back and to convert them into electrical signals able to be measured by the phase comparator 14.

The phase comparator 14, of a known kind, is able to measure the phase difference between the signal coming from the sinusoidal generator 23 and the one received by the optical receiver 16 through the fibre segment 50.

5 In particular, the phase comparator 14 is able to measure the phase difference between the continuous sinusoidal signal, generated by the sinusoidal generator 23, and the pulsed sinusoidal signal reflected back, received by the optical receiver 16 and to transmit such information, through a  
10 corresponding connection, to the processor 18.

The processor 18, of a known kind, is able, on the basis of programs developed during the design of the apparatus 10, to control the different devices of the instrument 10, and in particular the optical source 11, the impulse generator 24,  
15 the sinusoidal generator 23, the phase comparator 14 and the optical receiver 16 and to calculate and display the results of the measurements of the phase difference and group delay as a function of wavelength, based on the information from the phase comparator 14.

20 In particular, the processor 18 is able to adjust the duration and repetition frequency of the pulses generated by the pulse generator 24 on the basis of the characteristics of the fibre segment 50 being measured, such as length, presence of any intermediate connectors between the first termination  
25 and the reflecting termination 51, etc.

The duration of the impulses (Fig. 2), for instance, is determined by the processor 18 (Fig.1, Fig.2) in such a way that it is no greater than twice the time of propagation of the pulses themselves in the fibre segment 50 being measured.  
30 In the same way, the periodicity or repetition period of the impulses, for instance, is determined by the processor 18 in such a way that it is no less than 4 times the propagation time between the two ends in the fibre segment 50 being measured.



The conditions indicated above for the duration of the impulses and the repetition period of the impulses themselves are, as the person skilled in the art will readily comprehend, such as to allow the phase comparator 14 to  
5 selectively measure the phase difference between the sinusoidal signal generated by the sinusoidal generator 23 and the sinusoidal signal reflected by the reflecting termination 51.

The processor 18 is also able to inhibit the operation  
10 of the phase comparator 14, by means of the respective control connection, during the reflections from all optical connectors (including the connector at the first termination) present in the fibre segment 50 being measured. This inhibition, in particular, is effected in synchrony with the  
15 impulses generated by the impulse generator 24 thanks to the connection between the pulse generator 24 itself and the phase comparator 14.

The processor 18 is also able to control the optical receiver 16, by means of the respective control connection,  
20 adjusting some operating parameters such as gain, bandwidth, etc., according to the characteristics of the signals received by the optical receiver 16 itself.

The operation of the apparatus 10 according to the invention is as follows.

25 The modulated optical signal, generated by means of the combination of the signals coming from the optical source 11 and of the signal generator 12 (Fig. 2) is sent to the first end of the fibre 50 through the coupling device 15 and propagates to the opposite end of the fibre where it is  
30 reflected by the reflecting termination 51 and returns to the coupling device 15.

The coupling device 15 sends the optical signal reflected by the reflecting termination 51 to the optical receiver 16, where it is converted into an electrical signal and

transmitted to the phase comparator 14 for the measurement of the phase difference between the sinusoidal signal generated locally by the sinusoidal generator 23 and the one reflected by the reflecting termination 51.

5 The phase shift between the two sinusoidal signals is proportional, as is well known, to the group delay of the fibre 50 at the working wavelength of the optical source 11 and, therefore, by repeating the operations described above with a determined number of optical signals of various  
10 wavelengths it is possible to calculate, in a known manner, by means of the processor 18, the chromatic dispersion CD of the fibre segment 50.

Thanks to a first characteristic of the present invention, the apparatus or instrument 10 allows to certify  
15 or measure the chromatic dispersion CD of a fibre segment 50 accessing a single end of the fibre 50 itself. This considerably simplifies and abbreviates the measuring procedure.

Moreover, the measurements can be performed, at least in the  
20 case in which the fibre 50 is terminated at the second end with a not-angled connector, by a single operator instead of two as is the case with known instruments.

According to an additional characteristic of the present invention, the reference signal for measuring the phase  
25 difference is available inside the instrument and need not be obtained from a GPS receiver as in the known case taken as a reference.

The invention was described taking as reference impulse modulation signals, variable in amplitude in sinusoidal  
30 fashion, but, as a person versed in the art will readily comprehend, the amplitude variations of the impulse signals can have any shape, for instance triangular or square, as long as they are such as to allow a phase shift measurement between the generated signal and the reflected signal.

Obvious modifications or variations are possible to the above description, in the dimensions, shapes, materials, components, circuit elements, connections and contacts, as well as in the details of the circuitry and of the illustrated construction and of the method of operation, without thereby departing from the spirit of the invention as specified in the claims that follow.

**Claims**

1. Apparatus (10) for measuring the chromatic dispersion (CD) of an optical fibre (50), comprising:

- an optical source (11) able to generate optical signals at  
5 variable wavelength;

- a signal generator (12) able to generate modulation  
signals;

- a modulator (19) able to generate modulated optical signals  
on the basis of said optical signals and of said modulation  
10 signals;

- a coupler (15) able to send said modulated optical signals  
to a first end of said fibre (50):

characterised in that

- said signal generator (12) comprises means able to generate  
15 impulsive electrical signals having variable amplitude, and  
duration and periodicity determined according to the  
characteristics of said fibre (50);

- said fibre (50) comprises in correspondence with a second  
end a reflecting element (51) able to reflect said modulated  
20 optical signals and to generate reflected optical signals  
having a reflected modulation component; and by

- comparison means (14, 16, 18) associated to said first end  
of said fibre (50) and able to measure the phase difference  
between said modulation signals and said reflected modulation  
25 component.

2. Apparatus (10) as claimed in claim 1 characterised in that

- said coupler (15) comprises means able to receive said  
reflected optical signals; and

- said comparison means (14, 16) comprises

30 - an optical receiver (16) connected to said coupler  
(15) and able to convert said reflected optical signals into  
electrical signals representative of said reflected  
modulation component; and

- a phase comparator (14) connected to said signal generator (12) and to said optical receiver (16) and able to generate an electrical signal representative of said phase difference.

5 3. Apparatus as claimed in claim 1 or 2 characterised by

- control means (18) associated respectively to said optical source (11) and to said signal generator (12) and able selectively to control the wavelength of said optical signals and the characteristics of said modulation signals.

10 4. Apparatus as claimed in claim 3 characterised in that said control means (18) comprise

- computing means (18) able to calculate the chromatic dispersion (CD) of said optical fibre (50) on the basis of the phase difference measured as the wavelength of said optical signal varies.

15 5. Method for measuring the chromatic dispersion (CD) of an optical fibre (50) characterised by the steps of

- generating optical signals (11) at variable wavelength;  
- generating modulation signals (12) shaped by impulse electrical signals having predetermined phase, variable amplitude, duration and periodicity determined according to the characteristics of said fibre;

20 - modulating said optical signals (19) with said modulation signals;

25 - sending the optical signals modulated with said modulation signals to a first end of said fibre (50);

- reflecting at a second end of said fibre (51) said modulated optical signals in such a way as to obtain reflected optical signals having a reflected modulation component;

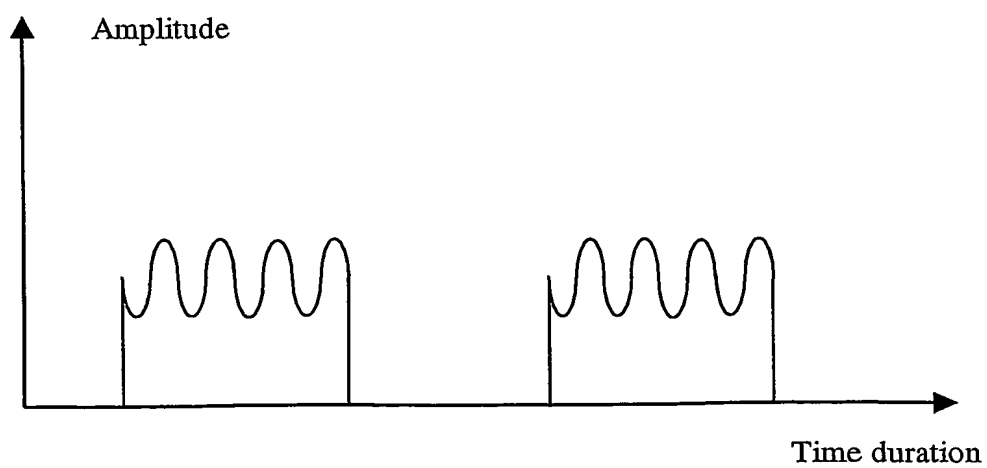
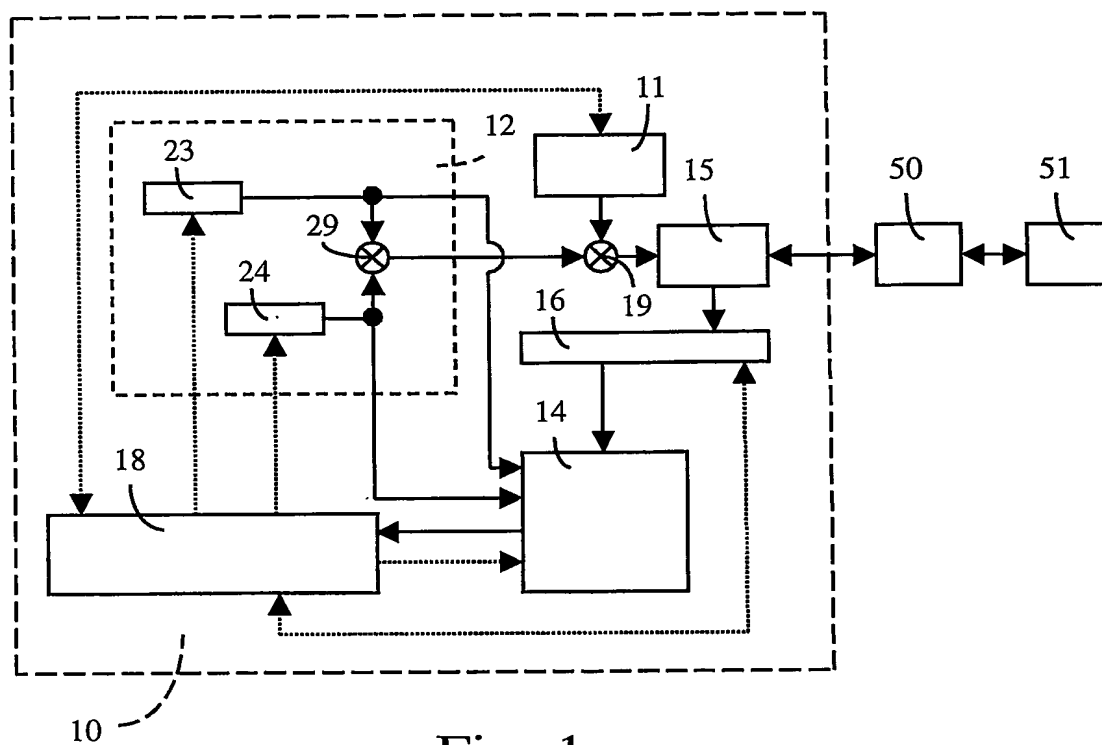
30 - measuring in correspondence with said first end the phase difference between said modulation signal and said reflected modulation component.

6. Method as claimed in claim 5 characterised by the additional step of

- calculating (18) the chromatic dispersion (CD) of said optical fibre (50) on the basis of the phase difference

5 measured as said wavelength of said optical signals varies.

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A. CLASSIFICATION OF SUBJECT MATTER  
IPC 7 G01M11/00

**According to International Patent Classification (IPC) or to both national classification and IPC**

### B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
IPC 7 G01M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

WPI Data, EPO-Internal, PAJ

### C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	FR 2 601 134 A (ALPHATRONIX SA) 8 January 1988 (1988-01-08) claims 1-20 ---	1-6
Y	FR 2 812 144 A (ADVANTEST CORP) 25 January 2002 (2002-01-25) claims 1-9 ---	1-6
A	EP 1 160 559 A (AGILENT TECHNOLOGIES INC A DEL) 5 December 2001 (2001-12-05) page 3 -page 9 ---	1-6
A	WO 02 16901 A (BRENDL JUERGEN ;LUCIOL INSTR (CH)) 28 February 2002 (2002-02-28) claims 1-20 ---	1-4
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☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

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- \*Y** document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- \*&** document member of the same patent family

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## INTERNATIONAL SEARCH REPORT

PCT/IT 02/00223

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6 310 993 B1 (CAO SIMON X F ET AL) 30 October 2001 (2001-10-30) claims 1-18 ---	1-6
A	US 5 428 697 A (DOLFI DANIEL ET AL) 27 June 1995 (1995-06-27) claims 1-22 -----	1

## INTERNATIONAL SEARCH REPORT

PCT/IT 02/00223

Patent document cited in search report		Publication date		Patent family member(s)	Publication date
FR 2601134	A	08-01-1988	FR	2601134 A1	08-01-1988
			WO	8800336 A1	14-01-1988
FR 2812144	A	25-01-2002	JP	2002022611 A	23-01-2002
			DE	10133336 A1	31-01-2002
			FR	2812144 A1	25-01-2002
			GB	2369431 A	29-05-2002
			US	2002085194 A1	04-07-2002
EP 1160559	A	05-12-2001	US	6407805 B1	18-06-2002
			EP	1160559 A2	05-12-2001
			JP	2002048679 A	15-02-2002
WO 0216901	A	28-02-2002	AU	7664201 A	04-03-2002
			WO	0216901 A2	28-02-2002
US 6310993	B1	30-10-2001	AU	2586101 A	03-07-2001
			EP	1257857 A1	20-11-2002
			WO	0146730 A1	28-06-2001
			US	2001028759 A1	11-10-2001
US 5428697	A	27-06-1995	FR	2699295 A1	17-06-1994
			DE	69325784 D1	02-09-1999
			DE	69325784 T2	09-03-2000
			EP	0603036 A1	22-06-1994